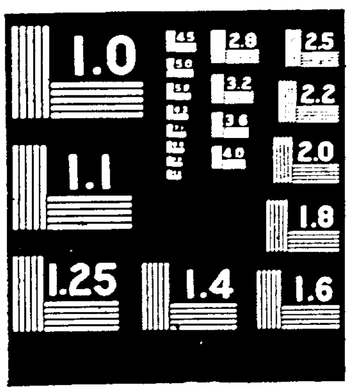
1 OF 1

AD 723865



WOODS HOLE OCEANOGRAPHIC INSTITUTION
Woods Hole, Massachusetts

REFERENCE NO. 71-26

THE SOUND CHANNEL AXIS IN THE WESTERN MEDITERRANEAN

by

Eli Joel Katz

May 1971

TECHNICAL REPORT

Supported by the Office of Naval Research under contract N0014-70-C-0205.

Approved for Distribution J. R. Heirtzler

J. R. Heirtzler, Chairman
Department of Geology and Geophysics

UNCLASSIFIED
Security Classification

DOCUMENT CONTROL DATA - R&D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1. ORIGINATING ACTIVITY (Corporate author) Woods Hole Oceanographic Institution Woods Hole, Massachusetts	2a. REPORT SECURITY CLASSIFICATION Unclassified 2b. GROUP

3. REPORT TITLE

THE SOUND CHANNEL AXIS IN THE WESTERN MEDITERRANEAN

4. DESCRIPTIVE NOTES (Type of report and inclusive dates)

TECHNICAL REPORT

5. AUTHOR(S) (Last name, first name, initial)

Eli Joel Katz

6. REPORT DATE	7a. TOTAL NO. OF PAGES	7b. NO. OF REFS
May 1971	11	14

8a. CONTRACT OR GRANT NO. N00014-70-C-0205 b. PROJECT NO. c. d.	9a. ORIGINATOR'S REPORT NUMBER(S) REFERENCE NO. 71-26 9b. OTHER REPORT NO(S) (Any other numbers that may be assigned this report)

10. AVAILABILITY/LIMITATION NOTICES

11. SUPPLEMENTARY NOTES	12. SPONSORING MILITARY ACTIVITY Office of Naval Research Ocean Science & Technology Division Arlington, Virginia 22217

13. ABSTRACT

The effect of the subsurface current on the sound velocity field in the western Mediterranean was investigated in the summer of 1970. This water movement carries warm waters from the Strait of Sicily to the Strait of Gibraltar at depths below the sound channel axis. A hydrographic section made between the two straits indicates that a change in the properties of the intermediate water at around 7°E results in a doubling of the depth of the sound channel axis and alters the character of the sound velocity profile about this axis. A more extensive study of this region, including towing of an instrument package, gave indications of an intermittent process involved in this change. The sound velocity field was found to change appreciably over distances of ten nautical miles. A second tow exercise probed the region between the Strait of Sicily and the Tyrrhenian Sea. It found the velocity field there to be less variable than might have been expected.

DD FORM 1 JAN 64 1473

UNCLASSIFIED
Security Classification

Unclassified

Security Classification

14. KEY WORDS	LINK A ROLE	LINK A WT	LINK B ROLE	LINK B WT	LINK C ROLE	LINK C WT
1. Western Mediterranean 2. Sound Channel 3. Levantine Intermediate Water						

INSTRUCTIONS

1. ORIGINATING ACTIVITY: Enter the name and address of the contractor, subcontractor, grantee, Department of Defense activity or other organization *(corporate author)* issuing the report.

2a. REPORT SECURITY CLASSIFICATION: Enter the overall security classification of the report. Indicate whether "Restricted Data" is included. Marking is to be in accordance with appropriate security regulations.

2b. GROUP: Automatic downgrading is specified in DoD Directive 5200.10 and Armed Forces Industrial Manual. Enter the group number. Also, when applicable, show that optional markings have been used for Group 3 and Group 4 as authorized.

3. REPORT TITLE: Enter the complete report title in all capital letters. Titles in all cases should be unclassified. If a meaningful title cannot be selected without classification, show title classification in all capitals in parenthesis immediately following the title.

4. DESCRIPTIVE NOTES: If appropriate, enter the type of report, e.g., interim, progress, summary, annual, or final. Give the inclusive dates when a specific reporting period is covered.

5. AUTHOR(S): Enter the name(s) of author(s) as shown on or in the report. Enter last name, first name, middle initial. If military, show rank and branch of service. The name of the principal author is an absolute minimum requirement.

6. REPORT DATE: Enter the date of the report as day, month, year; or month, year. If more than one date appears on the report, use date of publication.

7a. TOTAL NUMBER OF PAGES: The total page count should follow normal pagination procedures, i.e., enter the number of pages containing information.

7b. NUMBER OF REFERENCES: Enter the total number of references cited in the report.

8a. CONTRACT OR GRANT NUMBER: If appropriate, enter the applicable number of the contract or grant under which the report was written.

8b, 8c, & 8d. PROJECT NUMBER: Enter the appropriate military department identification, such as project number, subproject number, system numbers, task number, etc.

9a. ORIGINATOR'S REPORT NUMBER(S): Enter the official report number by which the document will be identified and controlled by the originating activity. This number must be unique to this report.

9b. OTHER REPORT NUMBER(S): If the report has been assigned any other report numbers *(either by the originator or by the sponsor)*, also enter this number(s).

10. AVAILABILITY/LIMITATION NOTICES: Enter any limitations on further dissemination of the report, other than those imposed by security classification, using standard statements such as:

(1) "Qualified requesters may obtain copies of this report from DDC."

(2) "Foreign announcement and dissemination of this report by DDC is not authorized."

(3) "U. S. Government agencies may obtain copies of this report directly from DDC. Other qualified DDC users shall request through ______________."

(4) "U. S. military agencies may obtain copies of this report directly from DDC. Other qualified users shall request through ______________."

(5) "All distribution of this report is controlled. Qualified DDC users shall request through ______________."

If the report has been furnished to the Office of Technical Services, Department of Commerce, for sale to the public, indicate this fact and enter the price, if known.

11. SUPPLEMENTARY NOTES: Use for additional explanatory notes.

12. SPONSORING MILITARY ACTIVITY: Enter the name of the departmental project office or laboratory sponsoring *(paying for)* the research and development. Include address.

13. ABSTRACT: Enter an abstract giving a brief and factual summary of the document indicative of the report, even though it may also appear elsewhere in the body of the technical report. If additional space is required, a continuation sheet shall be attached.

It is highly desirable that the abstract of classified reports be unclassified. Each paragraph of the abstract shall end with an indication of the military security classification of the information in the paragraph, represented as *(TS), (S), (C), or (U)*.

There is no limitation on the length of the abstract. However, the suggested length is from 150 to 225 words.

14. KEY WORDS: Key words are technically meaningful terms or short phrases that characterize a report and may be used as index entries for cataloging the report. Key words must be selected so that no security classification is required. Identifiers, such as equipment model designation, trade name, military project code name, geographic location, may be used as key words but will be followed by an indication of technical context. The assignment of links, roles, and weights is optional.

Unclassified

Security Classification

ABSTRACT

The effect of the subsurface current on the sound velocity field in the western Mediterranean was investigated in the summer of 1970. This water movement carries warm waters from the Strait of Sicily to the Strait of Gibraltar at depths below the sound channel axis. A hydrographic section made between the two straits indicates that a change in the properties of the intermediate water at around 7°E results in a doubling of the depth of the sound channel axis and alters the character of the sound velocity profile about this axis. A more extensive study of this region, including towing of an instrument package, gave indications of an intermittent process involved in this change. The sound velocity field was found to change appreciably over distances of ten nautical miles. A second tow exercise probed the region between the Strait of Sicily and the Tyrrhenian Sea. It found the velocity field there to be less variable than might have been expected.

Introduction

Existing data records have proved sufficient to give a broad description of the annual cycle of the typical sound velocity profile in the western Mediterranean and to differentiate between certain areas.(1),(2),(3) In the summer months the profile always consists of a high surface velocity, a strong gradient below, at most, a thin mixed surface layer, a sound channel axis most frequently at a depth about a hundred meters below the surface and a gradually increasing velocity with depth from the channel axis to the bottom. This typical profile is illustrated in Figure 1. The hydrographic reasons behind this particular type of profile are equally well known.(4),(5),(6) The surface waters reflect the combined result of seasonal interchange with the atmosphere and a strong influx of waters from the North Atlantic. The intermediate waters centered at depths between 300-500 meters are

---

Superior numbers in parentheses refer to similarly numbered references at the end of this paper.

constantly replenished by an influx from the eastern Mediterranean. The nearly homogeneous deeper waters, isolated in the western Mediterranean by high sills, are maintained by winter sinking at a constant temperature.

The present field study was motivated by the assumption that the key to the hydrographic stability of the western Mediterranean, and therefore the repeatability of the sound velocity profile encountered there, lies with an increased understanding of the intermediate water layer. This water is known to be a consequence of winter sinking of surface waters in the Levantine (whence its name, Levantine Intermediate Water), though the exact origin or origins are still a subject of research.(7) Coming from a region of high net evaporation relative to precipitation its most striking characteristic is its high saline content, which is about 39.1 $^{o}/oo$. With only about 1% dilution to its maximum value, it crosses the eastern Mediterranean and enters the western Mediterranean over a shallow and narrow sill in the Strait of Sicily*. Its main path through the western Mediterranean, as determined by tracing the location of the sub-surface salinity maximum, primarily follows the North African shelf. Its influence is evident, however, throughout the Tyrrhenian and Balearic Seas.

The sound channel axis lies between the surface and intermediate layers. For the most part, these two layers are flowing in opposite directions. Their integrated interaction will determine the actual depth and shape of the channel at a given location.

Throughout the warmer months, then, the picture in the large is a surface layer of fresh warm water overlying a colder, far more saline layer. This is a relatively stable

---

*Sill depth is given by Wüst(5) as 330 meters. A recent bathymetric chart (8) indicates a deeper channel connecting the eastern-western Mediterranean with a sill between 200-300 fathoms, though less than five kilometers wide in the straits.

situation and interaction will be very gradual. Consequently, large changes in the sound velocity profile do not occur in the western Mediterranean. On the smaller scale, about the core of intermediate water, the permanent sub-surface maximum in salinity is often coupled with a temperature inversion above it. At the depth of the inversion, the temperature gradient opposes the over-all gravitational stability of the water column imposed by the salinity gradient and a potentially more dynamic situation is present. It results in a modification to the intermediate water and one would want to assess the consequence to the sound velocity profile.

The Observations

The results of the observations can be divided into three parts. The first of these is a section of STD (salinity-temperature-depth) lowerings made along the axis of the flow of the Levantine Intermediate Water between the Straits of Gibraltar and Sicily. The second is a more detailed study, centered around a tow of an STD-type instrument package, made at a transition zone of the intermediate waters. The third is a similar study of conditions prevailing at the entrance of the intermediate waters into the Tyrrhenian Sea. In reducing the data, sound velocities were computed from Wilson's equation [9] and salinities were computed in a manner similar to that described by Pingree.[10]

A. Hydrographic Section Along the Axis of the Levantine Intermediate Water.

The location of the relevant lowerings and the resulting salinity section are shown in Figures 2 and 3. The latter quantifies the previous discussion. Relative to other presentations of similar sections,[4],[5],[11] it is a densely observed and quasi-synoptic section. The dominating feature of the section is the dramatic transition of the Levantine Intermediate Water from a high saline to a reduced saline core occurring in a limited region southwest of Sardinia. All other changes to the core are small in comparison.

A careful review of the historical sections show either a strong suggestion or a direct confirmation of this transition zone in the summer months. A meridional section presented by Miller[12] suggests that the zone is limited in the north-south direction as would be anticipated. The only previous comment on this transition was offered by Ouchinnikov and Fedoseyev.[13] They thought that it was caused by a turning north of the surface waters at about this longitude. This in turn, they suggested, was a result of the prevailing southerly winds off the African coast in the summer months as shown in the Middelland Zee Atlas.[14]

The geographic change in the salinity of the intermediate layer is reflected in the sound velocity field both above and below it. This is seen graphically in both partial sound velocity sections of Figure 4. In the upper section one notes that the sound channel axis, the dashed line, is permanently displaced to about twice its depth. The nature of the channel (i.e., broad relative to tight) has been altered as well. This is depicted in the figure by arbitrarily shading the depth layer where the sound velocity was less than one meter per second greater than the recorded velocity on the axis. The effect of the change to the intermediate water is seen, in the lower section, to extend down to about 800 meters below the surface.

Aside from the transition in profiles, the depth of the sound channel axis is found to be relatively variable once it has dropped in depth. There is no evidence to suggest that the undulation of the axis is repeatable. Furthermore, in a broad channel the actual depth of the sound velocity minimum will be an amplification of small changes in the sub-surface temperature. In such a case the variations are not particularly significant.

B. <u>Observations of the Transitional Region.</u>

Along the track A-B of Figure 2 a suite of oceanographic sensors was towed consecutively back and forth over a track of 60 n.m. at depths appropriate for studying the intermediate layer. The in-water components of this tow system, developed by Richard Nowak of the Woods Hole Oceanographic Institution, are shown in Figure 5. It was towed at speeds averaging around

six knots. The sensor outputs were digitally recorded on board ship in the same manner as during an STD lowering.

In presenting the results of the tow a potential sound velocity for the mean depth of the tow has been defined. The term 'potential' is introduced as allowances have been made for the oscillatory variation in the depth of the sensor package. Given the relatively weak vertical temperature and salinity gradients in the Mediterranean Sea at such intermediate depths, not to do so would have the effect of partially masking the variations due to temperature and salinity in the horizontal which is the effect being investigated. These depth variations (an artifact of the measurement) were removed by computing an average depth for each tow track and then basing the sound velocity on the in situ temperature and salinity combined with this average pressure.

The results of the tow are shown in Figure 6. The most significant feature to be seen is that on top of the intermittent small amplitude variation in sound velocity there is at least one and possibly other sections of anomalous measurements above the general level. The strongest anomaly of water, with sound velocities two to three meters per second above the background level, extends for about twenty kilometers.

The two tracks, at slightly different mean depths, both show the anomaly. The tracks approximately followed a line of latitude but were displaced at this point by about six n.m. in the meridional direction. Eight hours elapsed between the recordings of the peak sound velocity of each tow. The towed fish on each of the tracks experienced an alternating and substantial depth change, though wire played out and ship's speed remained unchanged. These changes in depth depended on tow direction in such a manner as to suggest a significant westerly sub-surface current.

The high values of sound velocity naturally resulted from high values of recorded temperature. The salinity was also abnormally high in these regions (as expected from density considerations). At the peak of the anomaly, temperatures higher than 14°C and salinities of 38.7 °/oo were

measured. Comparing these values to the temperature-salinity correlations obtained from the set of STD lowerings (not shown) yields the following description: the anomalous water is a relatively undiluted image of the water found coming over the sill at the Strait of Sicily.

Expendable bathythermographs launched at about ten kilometer intervals along the tow track confirm the origin of the anomalous water, though in a more ambiguous way because it can provide only a comparison in temperature. The bathythermograph record does, however, provide further information concerning the vertical extension of the phenomenon. Four pertinent traces are shown in Figure 7. Their location relative to the tow are indicated in Figure 6. For comparison purposes, the temperature profiles of three STD lowerings are also included in the latter figure.

There are several items to be discussed which are described graphically in Figure 7. Most importantly, it is noted that the anomalous water is not simply a thin lens of water at the tow depth. A comparison of Trace II with the remaining three shows that the anomaly extends over a depth of more than four hundred meters of the water column, including both the intermediate layer and the water above it. Tows over a wide range of depths would therefore have yielded similar sound velocity traces along the track. At depths between 200-300 meters the anomaly appears equally strong and even extends over a wider region than at the deeper tow depths.

The identification of each trace with a corresponding STD temperature profile is revealing, if not a completely reliable procedure. It has already been noted that the anomaly consists of waters whose origin can be identified as being most likely back at the straits. This is confirmed by the comparison of Trace II, obtained at the height of the anomaly, with the STD lowering at the mouth of the straits. The STD lowering made at the eastern end of the tow is repeated to either side of the anomaly (Traces I and III). It appears to be a true transitional profile and its actual measurement at site B must be considered totally circumstantial. It now appears that one could just have likely encountered a profile corresponding to Traces II or IV.

The earlier suggestion that the sound velocity section of Figure 4 could be considered as quasi-synoptic must be modified for this region. Horizontal inhomogeneities over distances of twenty kilometers are unlikely to be stationary in either time or space. The conclusion is that the area extending from the south of Sardinia to perhaps a degree of longitude west of the tow site is to a large extent unpredictable. A series of three STD lowerings made near site A (Figure 8) show the variation encountered there during one three-day period.

C. Observations at the Entrance to the Tyrrhenian Sea.

Along track C-D (Figure 2) overlapping tows were made consecutively at three selected depths. The track was selected as being over the most pronounced and deepest (greater than 500 fathoms) channel leading away from the sill in the Strait of Sicily [8]. It is the most likely path of the intermediate water from the straits into the Tyrrhenian Sea. It may also be, at least along its southern half, not far from the path of the intermediate water which is to turn westward and pass south of Sardinia into the Balearic Sea.

The depths of the tows were selected to be representative. The deepest is just at the core depth (maximum salinity). The second is above core depth but still in the intermediate layer. The last and shallowest was in the transition layer between the intermediate and surface layers. Each leg was about 65 n.m. The results are shown in Figure 9 employing the same manner of presentation as already discussed.

The shallowest tow, as might be expected given its depth and location, is the most variable. The root mean square sound velocity is one-half a meter per second. The two deeper depths show mainly patches of relatively homogeneous water without much variation in sound velocity between them. Their variance is a third of the shallow tow. The result indicates a rather smooth entrance of the intermediate

water into the western Mediterranean, which is in strong contrast to the conditions further downstream in the region of the first tow exercise.

Summary

This limited study has attempted to apply a causal approach to understanding the sound velocity structure in a particular area and season. Attention has been drawn toward the sub-surface waters and the sound channel axis, and away from the surficial waters. The latter are strongly weather dependent and are probably best approached on a statistical level. By further restricting the observations to the principal path of the intermediate water (paralleling the north African shelf), the results shown are probably the most severe example for the entire western Mediterranean.

The results can be restated succinctly. The presence of the Levantine Intermediate Water in the western Mediterranean has a strong influence on the depth and shape of the sound channel above it. When the intermediate water is forced to mix and be diluted with overlying waters, the sound channel is altered. This does not occur until it has travelled a considerable distance downstream of the sill. Where it does occur, southwest of Sardinia, the transitional stage is one where columns of water of different physical properties are found juxtaposed. The depth of the sound channel in this region has to be considered as largely unpredictable.

In the winter the problem is different. For the first part, published hydrographic sections made from data collections suggest that if regional mixing of the intermediate water occurs it is delayed until much further west. Moreover, the sound velocity profile is now quite different because of the colder surface water. There no longer is a sound channel but rather a monotonic increasing sound velocity with depth. Changes of the magnitude discussed here will not significantly alter the sound velocity profile in such circumstances.

Acknowledgements

It is a pleasure to acknowledge the assistance of both the scientific party and the ship's company on the Lisbon to Naples leg of cruise 59 of the research vessel ATLANTIS II. In particular, the Chief Scientist E. L. Murphy was instrumental in making the arrangements for the cruise and R. T. Nowak designed the tow system. Mrs. M. Jones wrote the basic data reduction programs. The work was performed under contract with the Office of Naval Research (CO-205) and is a part of the W.H.O.I. contribution to the Integrated Mediterranean Program.

LIST OF REFERENCES

(1) "Operational oceanography of the western Mediterranean Sea for submariners (U)", U.S. Naval Hydrographic Office, SP-49, 1962, (Confidential).

(2) "Acoustic structure of the western Mediterranean", R.B. Brockhurst, J. Underwater Acoustics, 16, pp. 121-129, 1966, (Confidential).

(3) "Velocity profile atlas of the Mediterranean and Black Seas (composite profiles)", Vol. 1, Nat. Ocean. Data Center, USL Pub. No. 1044-1, 1969.

(4) "Quelques traits generaux de l'hydrologie Mediterraneenne", Henri Lacombe and Paul Tchernia, Cahiers Oceano. 12, pp. 527-547, 1960.

(5) "On the vertical circulation of the Mediterranean Sea", Georg Wüst, J. Geophys. Res., 66, pp. 3261-3271, 1961.

(6) "Basic features of the geological structure, of the hydrologic regime and biology of the Mediterranean Sea", L.M. Fomin (ed.), Acad. Sci. (U.S.S.R.), Moskva Izdat. Nauka, 1965 (Engl. trans. AD 686 001, U.S. Dept. of Commerce).

(7) "On the origin of the Mediterranean intermediate water", S.A. Morcos, IUGG Abs. of Papers, V, 126, Sept. 1967.

(8) "Strait of Sicily: Bathymetry", Thos. D. Allan and Carlo Morelli, Saclant ASW Res. Center, La Spezia, Italy, 1970.

(9) "Speed of sound in sea water as a function of temperature, pressure and salinity", W.D. Wilson, J. Acoust. Soc. Amer., 32, pp. 1357, 1960.

(10) "In situ measurements of salinity, conductivity and temperature", R.D. Pingree, Deep-Sea Res., 17, pp. 603-610, 1970.

(11) "The water masses of the Mediterranean Sea", L.V. Moskalenko and I.M. Ouchinnikov, article included in (6), pp. 202-218a (in translation).

(12) "Physical oceanography in the Mediterranean Sea: a discourse", A.R. Miller, Rapports des reunions de la C.I.E.S.M.M., 17, pp. 857-871, 1963.

(13) "The horizontal circulation of the water of the Mediterranean Sea during the summer and winter seasons", I.M. Ouchinnikov and A.F. Fedoseyev, article included in (6), pp. 185-201 (in translation).

(14) "The Mediterranean, Oceanographic and Meteorological data", Royal Netherlands Meteorological Inst., De Bilt, 1957.

LIST OF FIGURES AND LEGENDS

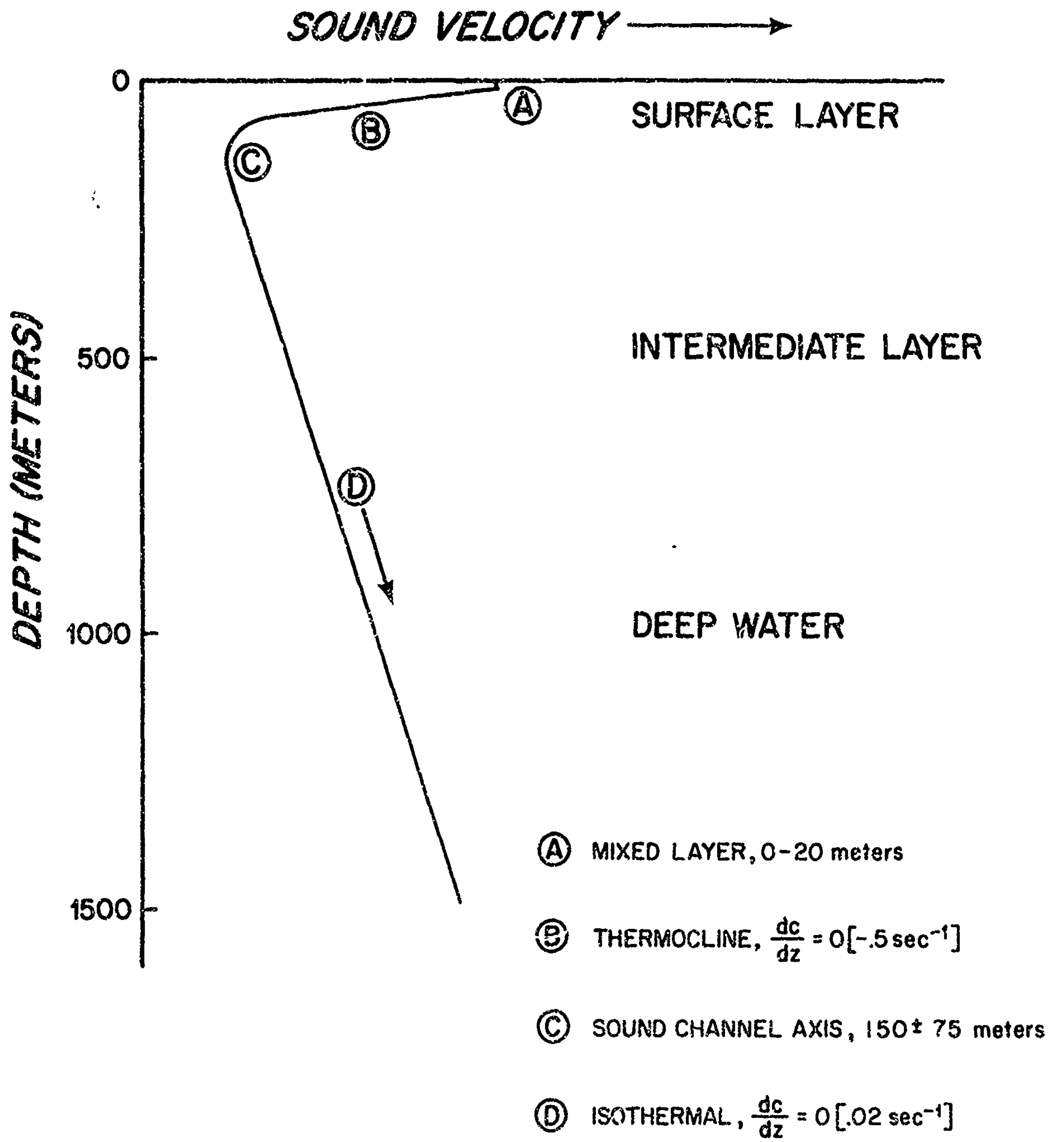


Figure 1. A generalization of the sound velocity profile found throughout the western Mediterranean in the summer months.

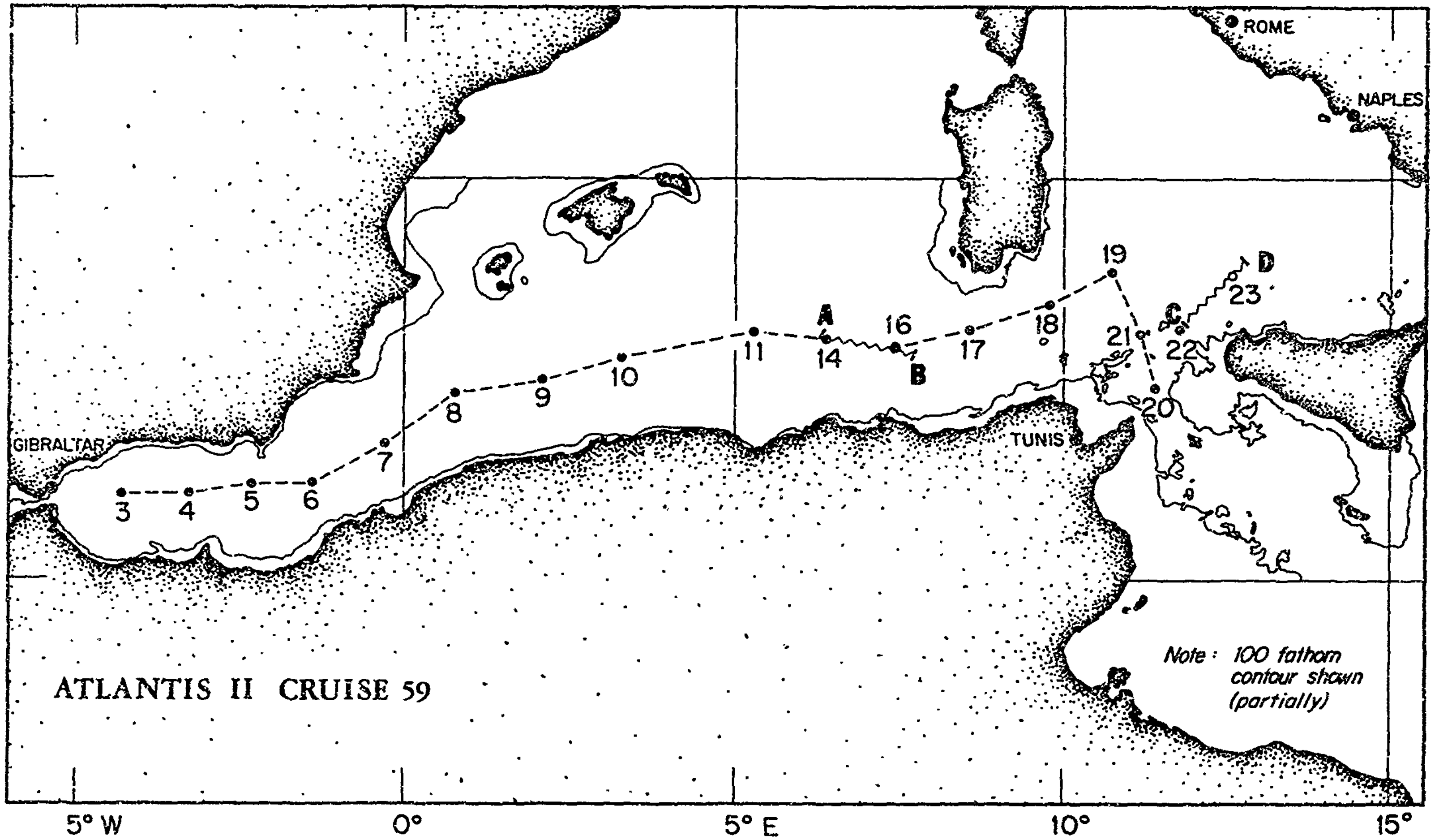


Figure 2. Location of relevant STD lowerings and tows (A-B, C-D) made during the period 9-22 July, 1970.

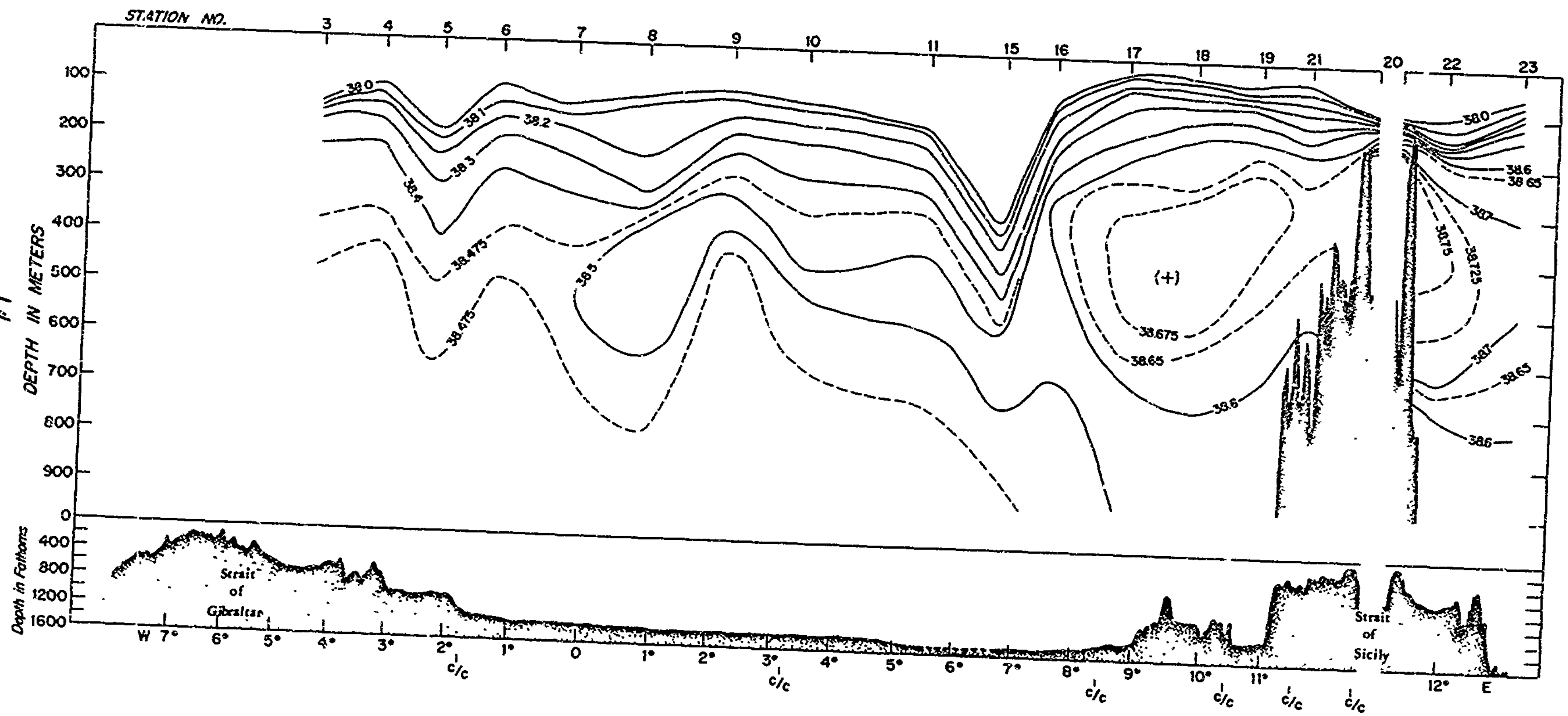


Figure 3. Salinity section along the western Mediterranean: salinity greater than 38.0 $^{0}/oo$.

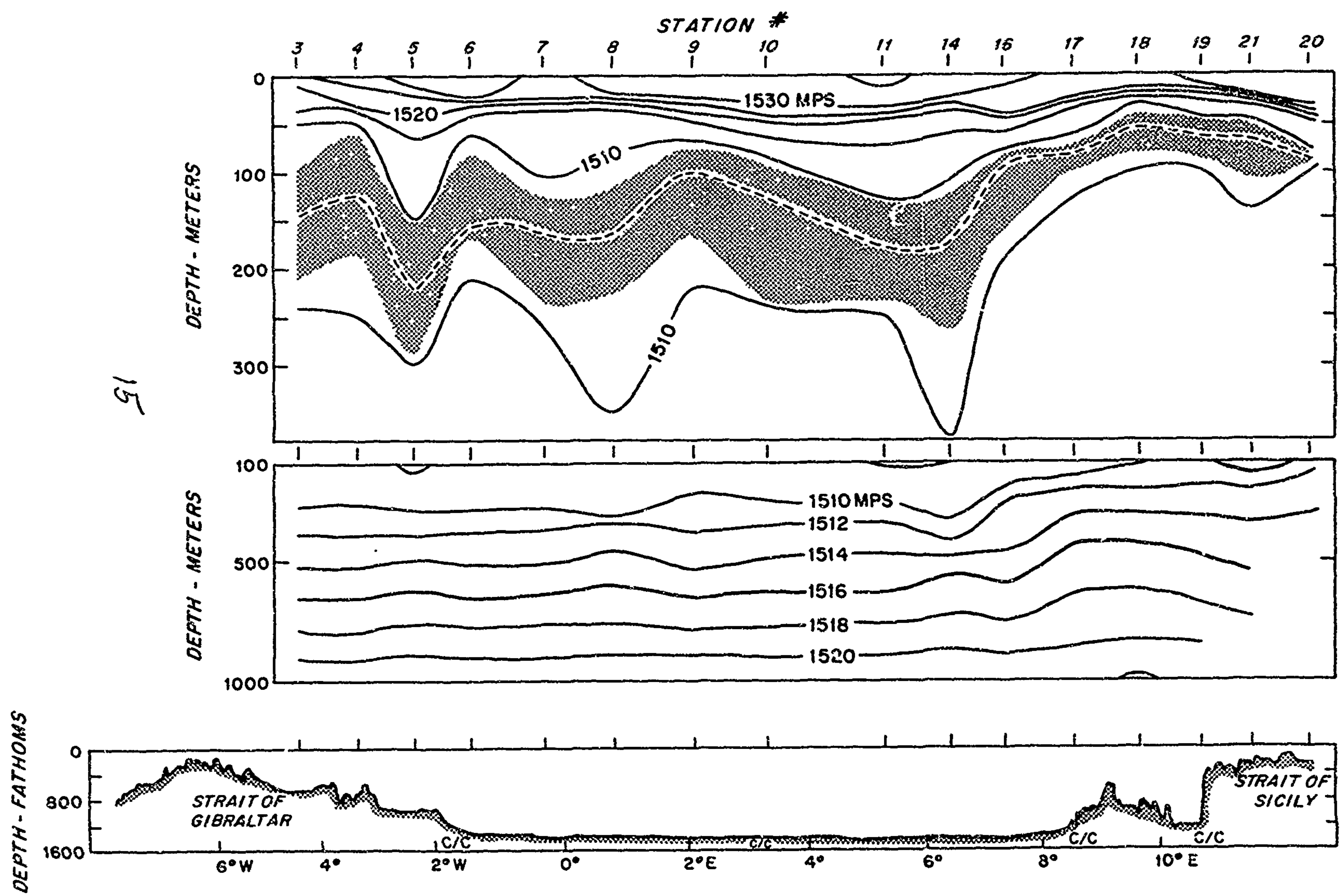
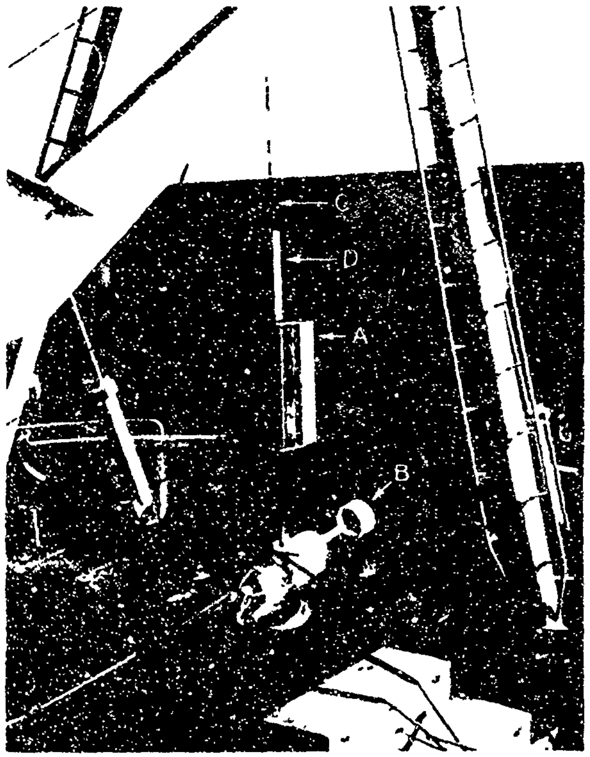


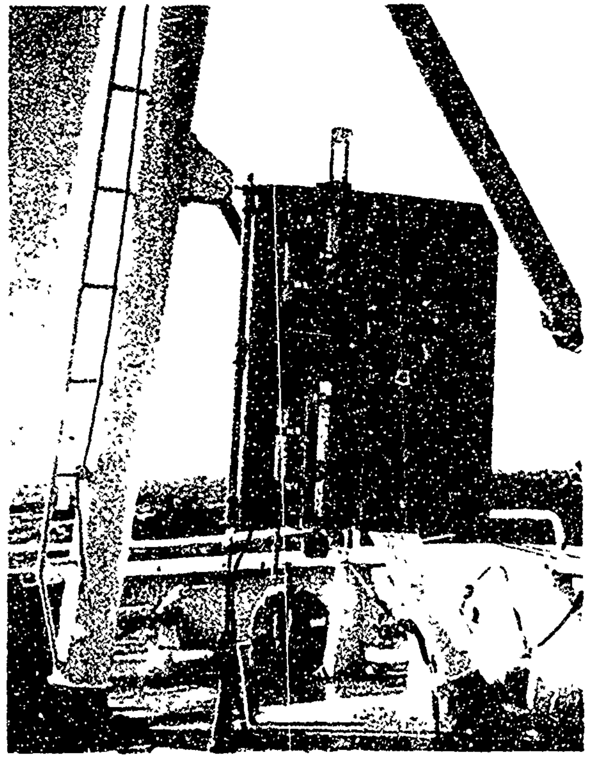
Figure 4. Sound velocity sections showing the sound channel axis (dashed line).

16



5a The major components:

A. Low drag housing for sensors.
B. Weighted (one ton) fish.
C. Multi-conducting, reinforced, tow cable.
D. Fairings (one shown).



5b. The four sensors mounted in housing: pressure, sound velocimeter, temperature, and conductivity.

Figure 5. Gear used for STD-type tows

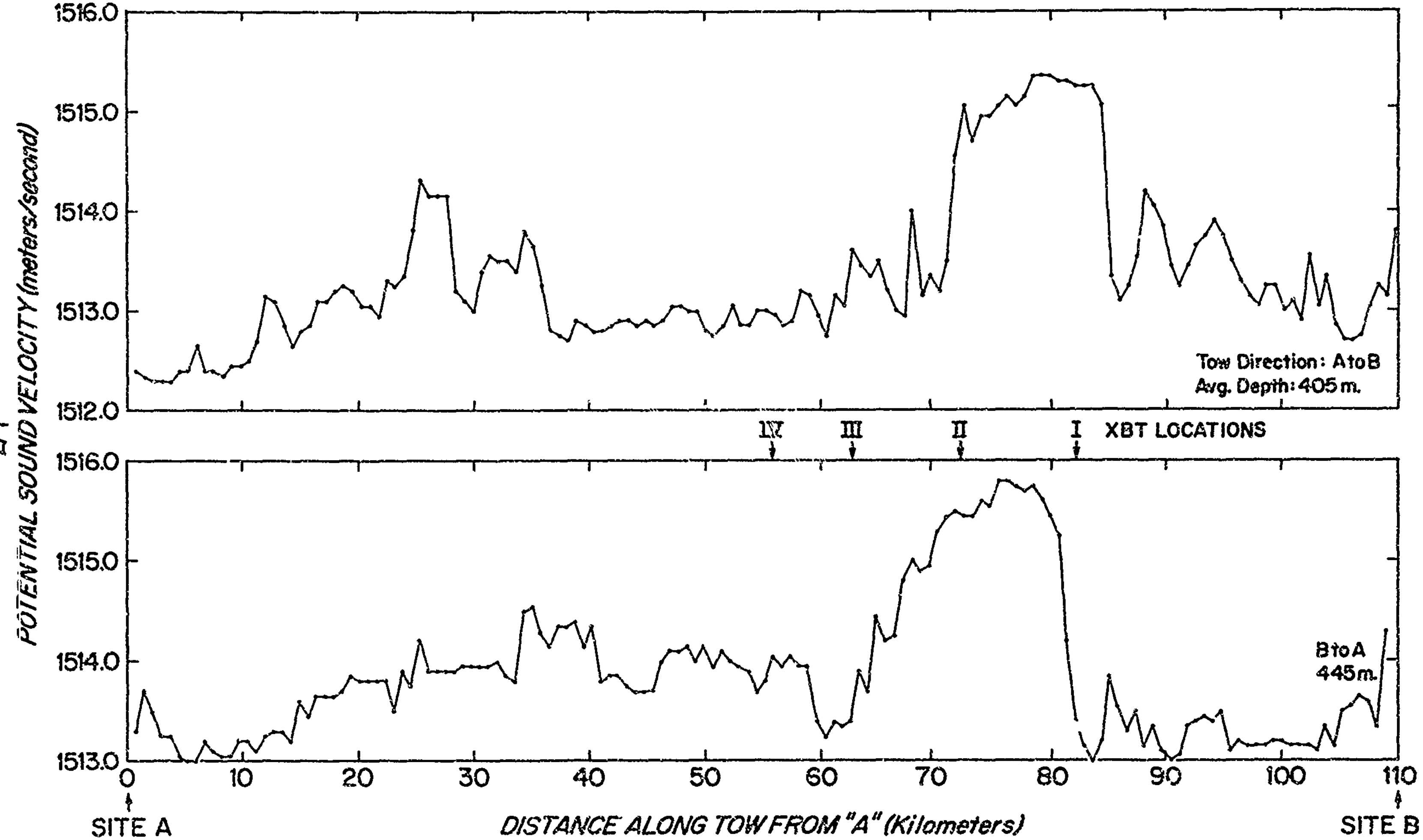


Figure 6. Computed sound velocity along track A-B. Each data point is an average over 30 meters (about six individual scans), once every 750 meters. The Roman numerals indicate the location of launching expendable bathythermographs discussed in the text.

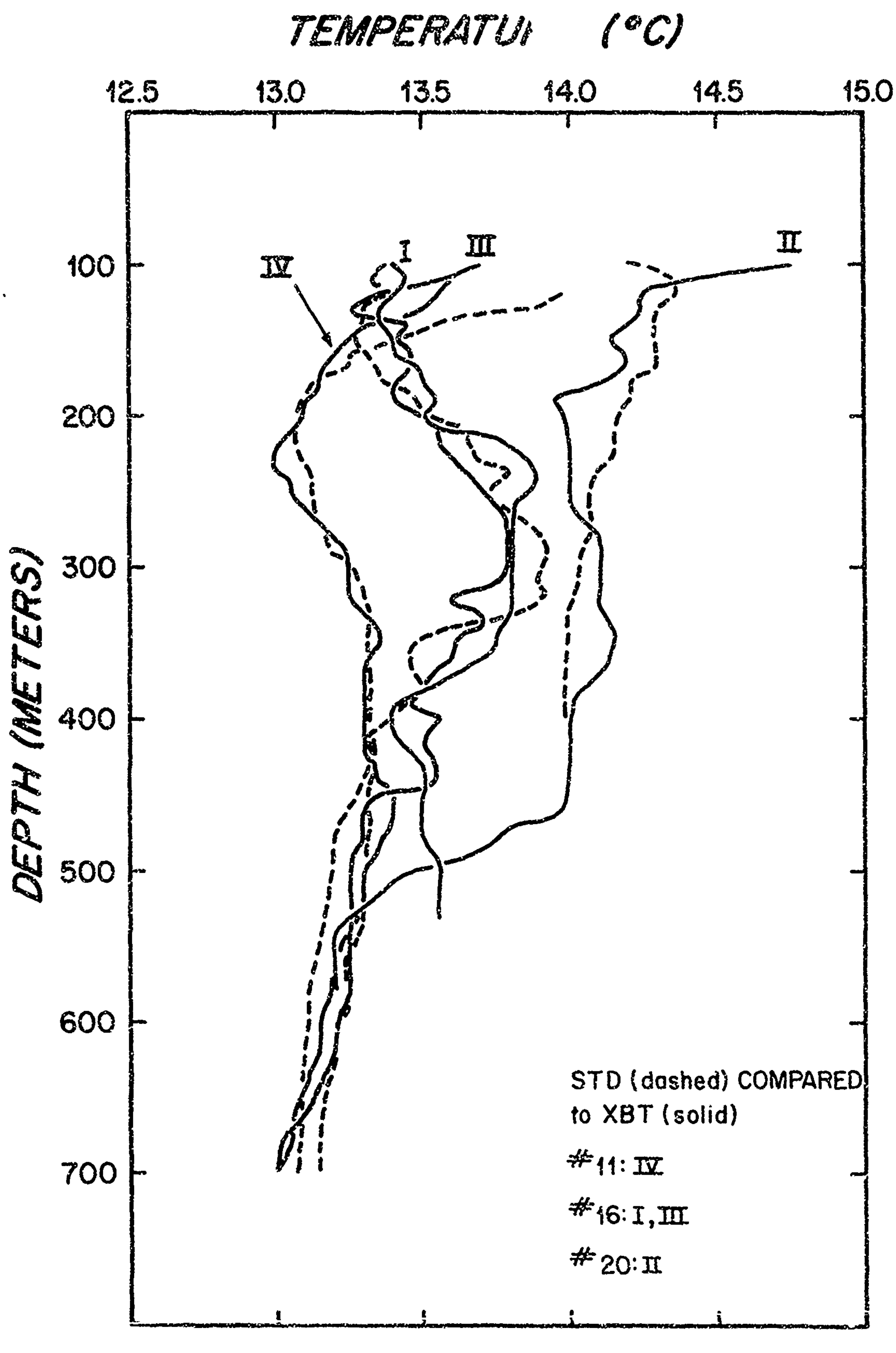


Figure 7. Comparative temperature traces from bathythermographs and STD lowerings.

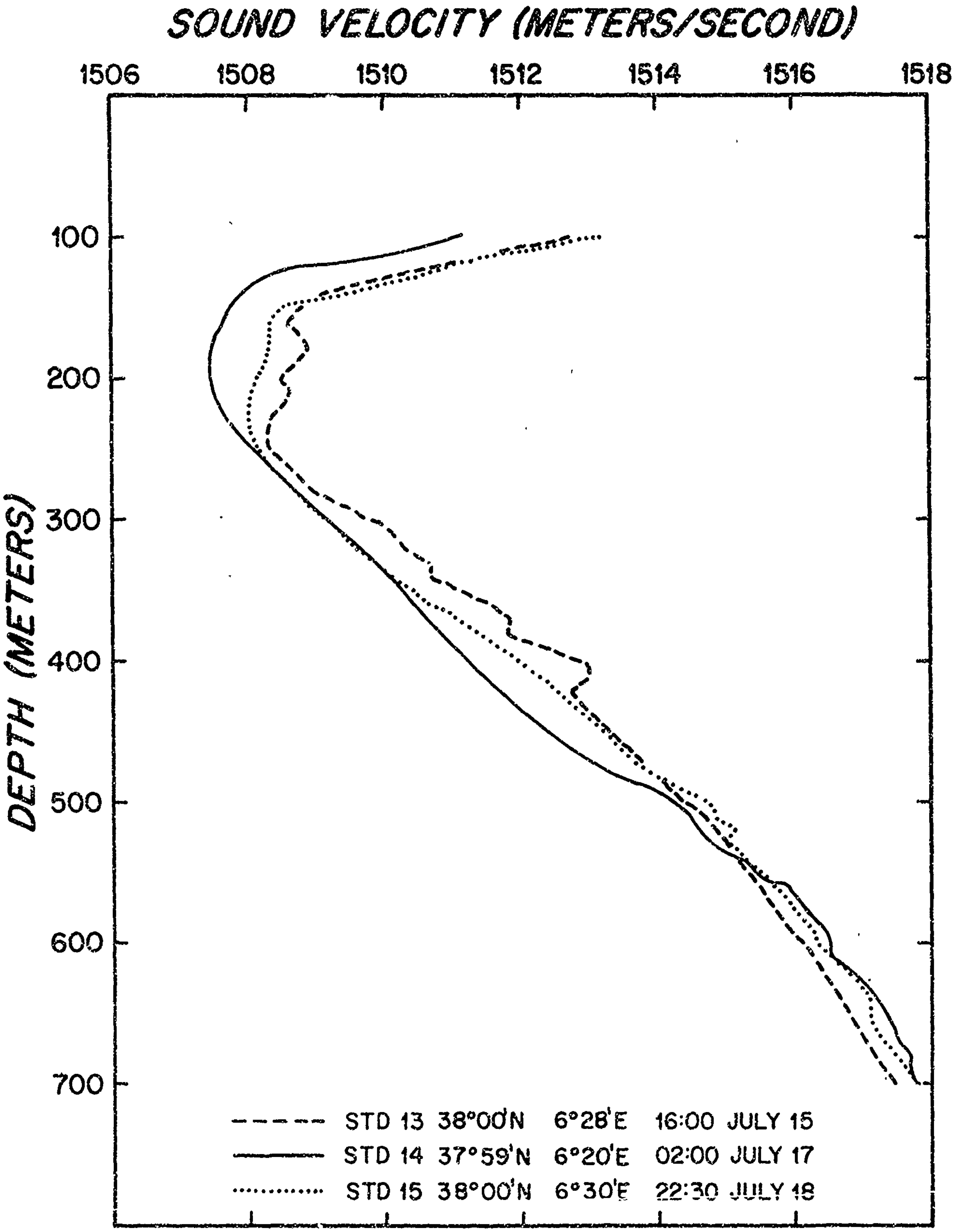


Figure 8. Computed sound velocity profiles from STD's near site A.

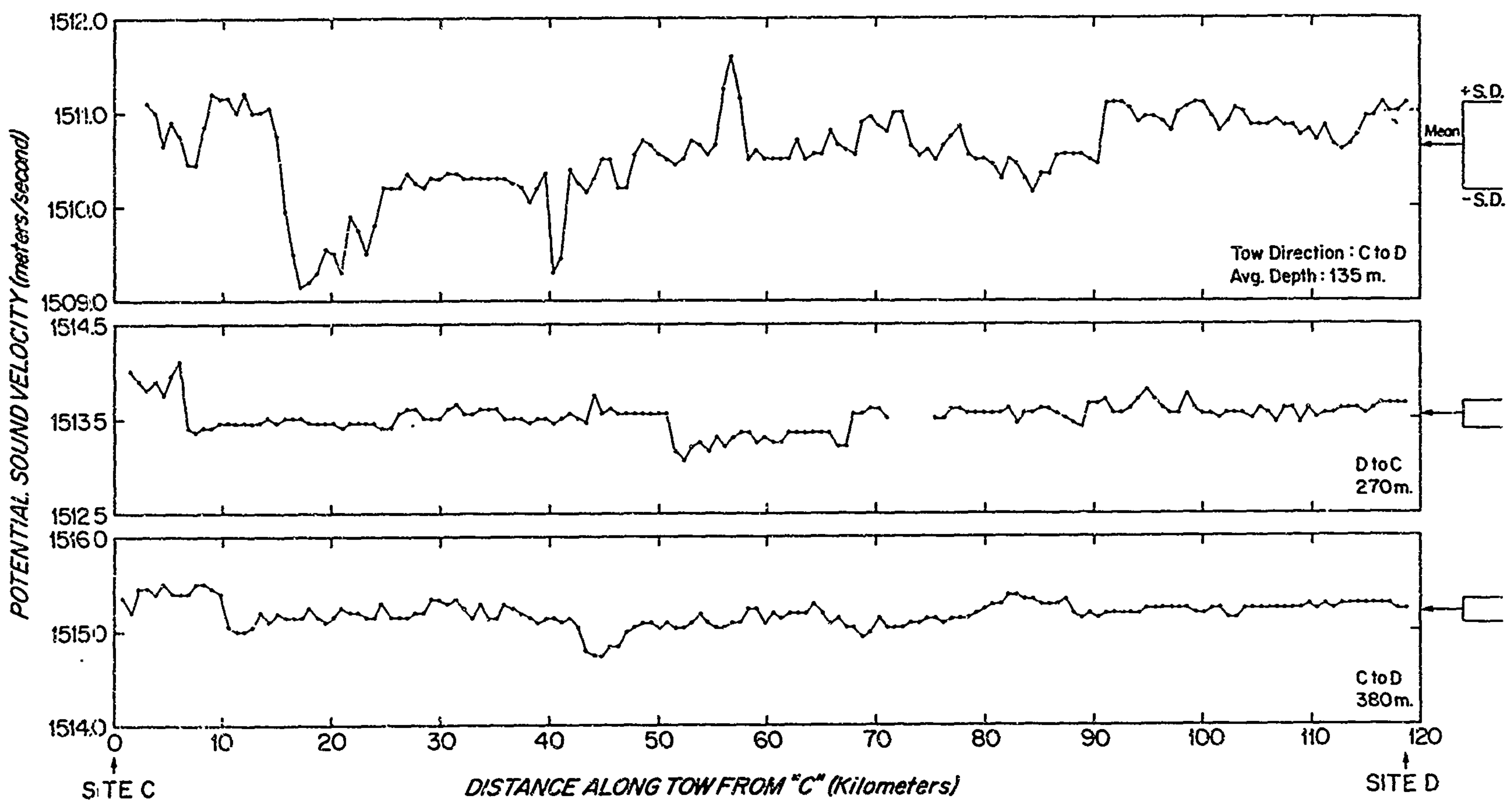


Figure 9. Computed sound velocity along track C-D.